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Topology Optimization of Coupled Photonic Crystal Cavities for Flat-top Drop Filter Functionality

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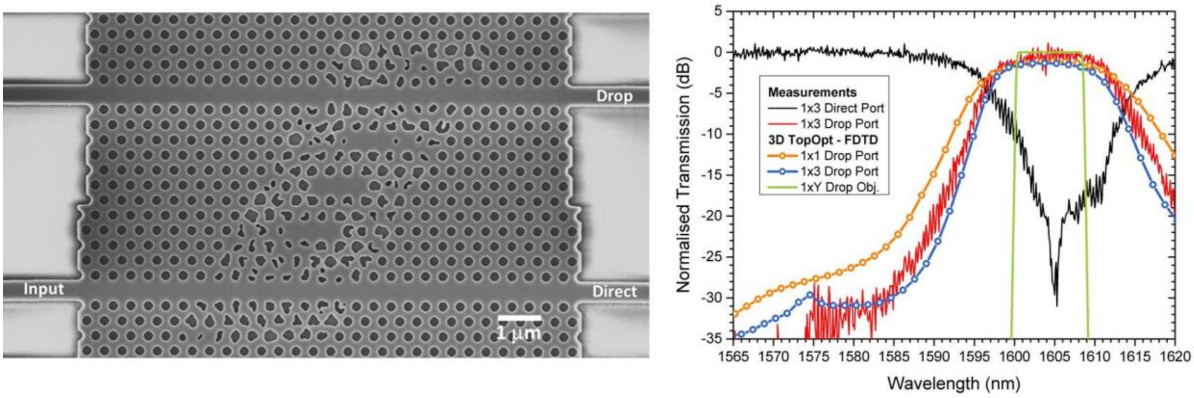
Wavelength-division multiplexing (WDM) filters desire a flat-top and unity pass-band bandwidth to ensure signal fidelity and to increase the tolerance to signal wavelength shifts [1, 2]. In silicon photonics such performance is typically obtained by utilizing e.g. a binary tree of cascaded Mach-Zehnder-like lattice filters [1] or coupled optical micro-ring resonators [2]. Moving away from conventional design solutions, it has been demonstrated that flat-top filter responses can be obtained by carefully designing the coupling and phase matching conditions between ultra-compact cavities in coupled photonic crystal (PhC) cavity systems [3]. However, designing PhC flat-top filters is not straight forward and may not give optimal solutions due to a limited design parameter space.

In this work, we apply 3D topology optimization (TopOpt) [4] to coupled PhC L3 cavities initially having a Lorentzian response and obtain a low-loss flat-top drop filter. Topology optimization is performed utilizing 3D finite-difference time-domain (FDTD) modeling with a modest 32 nm spatial and an ~0.75 nm spectral resolution using a software package developed in-house [5]. Experimental verification is done by optical characterization of optimized structures fabricated in silicon-on-insulator material. Figure 1(a) shows a scanning electron micrograph (SEM) image of a fabricated and topology optimized drop filter based on three coupled L3 PhC cavities (1x3), which are separated from each other by two rows of holes.



(a) (b)

Fig. 1 **(a)** SEM image of a fabricated and topology optimized drop filter based on three coupled L3 PhC cavities. **(b)** Normalised spectra measured for the drop (red) and the direct (black) port. Also shown is the box-like objective function used in the 3D TopOpt (green) and the drop spectra calculated for a 1x1 (orange) and a 1x3 (blue) topology optimized PhC cavity system. All spectra have been normalised to the transmission through a photonic wire.

Figure 1(b) shows the obtained spectra from TopOpt of a single (1x1, orange) and a 1x3 (blue) cavity system using an ~8 nm broad box-like objective function (green) for the desired drop response. As seen, both topology optimized cavity systems deliver a low-loss and flat-top response. However, the 1x3 cavity system has a sharper roll-off analogous to coupling multiple micro-ring resonators [2], but here exploiting the ultra-compact footprint of the PhC cavity system. Also shown in Fig. 1(b) are the measured and normalised spectra for the direct (black) and the drop (red) port of the fabricated 1x3 drop filter that experimentally verifies the modelled drop filter design. We believe that by applying TopOpt to a larger number of coupled PhC cavities a higher shape-factor of the box-like response can be achieved [2] and make topology optimized PhC cavity systems attractive candidates for ultra-compact WDM demultiplexing devices.

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